APPENDIX H: Change Analysis

Scenario 1. The mixer blade impacted solidified explosives that had been left in pot 5 in Booster Room 2 the previous day.

Scenario 2. Foreign materials or hard lumps of Comp-B or substitute materials that were added to the base mix in pot 5 caused a detonation due to impact, friction, or shearing.

Scenario 3. Electrostatic discharge or friction detonated PETN that had been added to the Pentolite in pot 4 and allowed to heat up without any TNT in the pot to dissolve the PETN and act as a lubricant.

Scenario 4. The breaking of lumps of Comp-B or harder or more sensitive substitute materials with a steel hammer caused a detonation outside the mixing pot due to impact or impingement of explosives between hammer and a foreign object in the material or another hard surface.

Each of the changes identified in the Change Analysis Table had some influence on the melt/pour operation in Booster Room 2. This analysis shows that specific conditions that were present in the room when the incident occurred could have caused the detonation. The investigation team concluded that Scenario 1 is the most likely cause of this incident. This conclusion is based on the analysis of the number and types of changes as well as the probable human interaction with those changes.

The investigation team believes that these change factors support the conclusion that the melt/pour operator in Booster Room 2 did not verify the contents of mixing pot 5. He turned on the mixing element of pot 5 with 50 to 100 pounds of solid explosive material in it. This action resulted in the detonation of the material in the pot, which then propagated to the rest of Booster Room 2 and then to the PETN Building and magazine. The explosion resulted in the death of four workers and the injury of six others.

There is a strong case for the conclusion that Scenario 1 caused the explosion. It assumes, however, that the operator did not look into the pot before turning on the mixer. If the operator did look into the pot and did not turn on the mixer, then Scenarios 2, 3, or 4 could explain how the detonation occurred.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Equipment Change				
1	Larger mixing pots were installed in Booster Room 2. The large mixing pots had an inside diameter of 46 inches. The smaller mixing pots in Booster Room 1 had diameters of less than or equal to 36 inches.	The larger pots had an inside radius of 23 inches, compared to an inside radius of 18 inches on the next-largest mixing pots used at the facility. This increased the surface area of the material left in the bottom of the larger pot. For the depth of material left in the pot, there was 27% more surface area. This would contribute to greater amounts of adhesion, crystal shearing, and rotational friction generated due to the mixing blade than from any previous configuration. This increased the likelihood of detonation due to friction, adhesion, or crystal shearing. It would also contribute to more rapid melting of material in the pot.	The larger capacity of the mixer allowed more material to be added during the initial steps of the process. Consequently, the operator could have added large amounts of the LX-14 and Comp-B to the pot. If this happened, then the material would be mixed in a dry configuration for several minutes before there was sufficient melting to reduce friction, eliminate impingement, or impact chunks of the explosive between the mixer blades and "breaker bars," or between the mixer blades and mixer walls. If foreign material was in the chunks, it could have caused additional friction or sparking until the material had melted.	Not Applicable	Not Applicable

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Equipment Change				
2	The larger mixing pots in Booster Room 2 had "breaker bars." These were not present in Booster Room 1.	Not Applicable	The "breaker bars" provided an additional component for the material to interact with during the mixing operation. If material were left in the bottom of mixing pot 5, then the working clearance between the "breaker bars" and the bottom of the mixer would be changed, possibly allowing impingement or impact to occur.	Not Applicable.	Not Applicable.
3	Wall thickness of larger mixing pots, including pot 5, compared to mixing pots used in Booster Room 1.	The heavier construction of the large mixing pots made them more rigid. Consequently, there would be little or no yielding when materials were forced between the mixing blades and walls of the pot. This, in combination with low-speed, high-torque mixing, could provide the motive force for a friction detonation of the material.	The heavier-walled pots were more rigid. As a result, there would be little or no yielding to materials between the mixing blades and walls. This, in combination with low-speed, high-torque mixing, could provide the motive force for a friction detonation of the material.	The heavier-walled pots were more rigid. Consequently, there would be little or no yielding to materials between the mixing blades and walls. This, in combination with low-speed, high-torque mixing, could provide the motive force for a friction detonation of the material.	Not Applicable.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Equipment Change				
4	The steam system's heat capacity was greater than the hot-water system used in Booster Room 1.	The steam-heat system in Booster Room 2 had a higher heat capacity than the hot water system in Booster Room 1. The operators were able to melt material faster, and the pots had less buildup of material on the internal components. The operators were used to working with "clean" pots in Booster Room 2. They were less concerned about the internal condition of the pots than when they worked in Booster Room 1.	The higher heating capacity of the steam system in Booster Room 2 allowed the operators to add larger chunks of material to the pots.	PETN with a higher moisture content was brought to Booster Room 2 because it could be dried out without causing a significant delay in production. The practice for starting the Pentolite pot in Booster Room 2 was to put the PETN in the pot and allow it to mix without other materials while it dried out. This occurred while the melt/pour operators were doing the setup, which typically would take about 20 minutes.	With the higher heat capacity of the steam system, there was less need to break up some of the chunks of material being added to the pots. Workers were used to doing this operation, however, from their experience working in Booster Room 1.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Process Change				
5	Normally, all material in the mixing pots was used up before the end of day shift. On this occasion, 50-100 lbs. of material was left in the pot at the end of the shift.	The material would harden overnight when the steam heat to the pot was reduced at the end of the shift. If the operator failed to look into the pot in the morning, he could have turned on the steam and then turned on the mixer with a large amount of solid explosive in the pot. This action could have resulted in a detonation due to crystal shearing, high friction in breaking the adhesion of the pot walls, or the friction of turning the material without any lubrication while the pot heated up.	The operator may have noticed that there was material in the pot. If he did, he would have waited about 10 minutes before adding the LX-14 or Comp-B to the mixer. On the surface, the pot contents may have looked liquid, but it is unlikely that the large mass of material would have been dissolved in this time frame. Adding chunks of material or material that could contain foreign objects in it could have provided a mechanism for detonation. The chunks may have been impacted or impinged during the mixing, friction in the dry mix may have been a detonation source, or metal objects in the mix could have been caught between the solid mass of residual mix and the bottom or sides of the mixing pot. All of these mechanisms may have been present.	If the operator noticed that pot 5 had a mass of material in the bottom, then he may have proceeded with the next step in his startup process, which would be to add PETN to the Pentolite pot 4.	If the operator recognized that there was material in the pot, he may then have decided to proceed with opening the LX-14 and Comp-B boxes. It was common practice at the facility to break up larger chunks of material using a steel hammer. This was done to reduce the time it takes for the material to melt. The process of breaking up the material included hitting the material in a shipping container, which could be located on the concrete floor or on another box of explosives. The operator may have been at this step of his process when the detonation occurred.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Process Change				
6	PETN added to the mixing pot without TNT	Not Applicable	Not Applicable	In Booster Room 1, the PETN was added after some liquid TNT was added to the Pentolite-mixing pot. The TNT acted as a lubricant, and allowed the PETN to go into solution soon after being added. The electrostatic-discharge conditions described in the Environmental Changes section of this table would not be present if this step were followed in Booster Room 2.	Not Applicable.
7	Comp-B added to base-mix pot without first adding liquid or melting solid TNT	Not Applicable	The company's written procedure describing proper operation of the melt/pour process directed that the TNT be added before the Comp-B materials. This would have ensured that the Comp-B, which often was chunky and sometimes had metal foreign materials, would have some lubrication and fluid to help protect it from friction, impingement, and impacts during its melting. Adding the Comp-B first	Not Applicable	Not Applicable

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Process Change				
			typically allowed a brief period of time when the material was still solid and thus susceptible to friction, impingement, or impact. If solid material left over from the previous evening were still in the pot, then it would increase the time of susceptibility.		
8	Single person operating the booster line instead of two people usually operating in Booster Room 2.	In Booster Room 1, two workers worked together in each production line. In Booster Room 2, only one person was operating each production line. This increased the number of tasks that needed to be performed, which increased the time pressures on the individual. This factor has a significant effect on human error. Time constraints affect decision processes and may influence individuals to take risks or act in unusual ways.	See explanation in Scenario 1 to the left.	Working by himself would increase the time between adding PETN and subsequently adding the TNT to the Pentolite pot.	See explanation in Scenario 1 to the left. Added time constraints and increased workload would have increased the likelihood of human error during the performance of this task.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Process Change				
9	Hot water to the mixing pots was normally left on in Booster Room 1. In Booster Room 2, only one valve was left "cracked" open on the mixing pots overnight.	Workers in Booster Room 1 would not expect to find hard material in the bottom of a mixing pot, even if they left material in the pot overnight. This would tend to reduce the dependence on checking the pots because generally there would not be any solid material in the pots. Because the worker running the production line the morning of the incident learned his trade in Booster Room 1, the possibility that the material would be hard in the morning may not have occurred to him.	Not Applicable	Not Applicable	Not Applicable
	Material Change				
10	LX-14 material had larger and harder chunks	Not Applicable	See Scenario 2, Item 5, discussion. Increasing the size and hardness of chunks makes this situation worse.	Not Applicable	See Scenario 4, Item 5, discussion. Increasing the size and hardness of chunks makes this situation worse.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Operator Change				
11	The operator in Booster Room 2 had been trained and was experienced in operating in Booster Room 1 on the second shift. He had been working the day shift in Booster Room 2 for approximately 8 weeks.	The operator in Booster Room 2 had received on-the-job training for the melt/pour operation while working on the second shift in Booster Room 1. At the start of the second shift, the mixing pots would be mixing and already hot. In some instances, some material might have been left in them. Second-shift operators do not need to turn the mixer motor on; therefore, the operator in booster Room 2 may not have developed a habit of looking into the mixer before turning the mixer on. Even if the on-the-job training emphasized this precaution, the worker would not do it when working on the second shift in Booster Room 1.	Not Applicable	Not Applicable	Not Applicable

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Operator Change				
		Also, because it was a common practice to leave the pot empty at the end of the shift, failure to perform a precautionary look into the mixing pot would not normally be dangerous.			
12	The second operator was not working the morning of the incident.	The second operator knew that there was material left in pot 5. Had he been in the room, he may have reminded his coworker about the material left in the pot the previous evening.	Not applicable. This person would follow similar work practices or would not have corrected the other individual's technique.	Not applicable. This person would follow similar work practices or would not have corrected the other individual's technique.	Not applicable. This person would follow similar work practices or would not have corrected the other individual's technique.
	Environmental Change				
13	Low temperature outside (low to mid twenties), 81% relative humidity.	Booster Room 2 did not have a heater. The practice of leaving one of the valves on the pot cracked a small amount may have been enough to keep the material semi-liquid under certain conditions. In this instance, the quantity of material left in the pot combined with the cold	The cooler the material was in pot 5, the longer it would take to heat to liquid state. Adding material before the solid mass left in the pot had turned to liquid would have increased the likelihood of friction, impingement, or impact of materials.	Humidity drops by a factor of approximately one-half for every 20°F of temperature rise. Based on this property of temperature and humidity, as the temperature inside the pot was raised toward 200°F, the relative humidity in the pot would approach 0%. Low humidity, combined with the PETN granules and the	Not Applicable.

Item #	Change Description	Effect on Scenario 1	Effect on Scenario 2	Effect on Scenario 3	Effect on Scenario 4
	Environmental Change				
		outside temperature would contribute to the material being in solid form on the morning of the incident.		mixing action, would create ideal conditions for electrostatic discharges, which could result in detonation of the PETN.	